Diagnostics, Monitoring and Mitigation of N2O Emissions from Wastewater Treatment Operations – Outcomes of the LAGAS project

Jensen, Marlene Mark; Smets, Barth F.; Ekström, Sara Elisabet Margareta; Vansgaard, A. K.; Lemaire, R.; Plósz, Benedek G.; Domingo-Felez, Carlos; Thamdrup, Bo; Ma, Chun; Delre, Antonio; Scheutz, Charlotte; Thornberg, D.

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Abstract

Nitrous oxide (N$_2$O) is a potential ozone depleter and strong greenhouse gas (GHG), with a warming potential ~300 times higher than carbon dioxide (CO$_2$). Anthropogenic N$_2$O emissions - of which 1.2% originate from the wastewater treatment (WWT) sector - is increasing at alarming rates. The goals of the LaGas project were to quantify N$_2$O emissions, and identify and quantify the mechanisms and factors controlling N$_2$O production and emissions from both conventional and recent biological N removal technologies, and to capture this information in novel predictive models with the aim to identify and implement mitigation strategies to control N$_2$O emissions.

With the tracer gas dispersion method, we quantified a plant-integrated GHG emission of five WWT plants (WWTPs), representing different configurations. The emission factors for CH$_4$ ranged between 0.2 to 3.2% of the influent organic carbon, while the N$_2$O emission factor ranged between 0.1 to 5.2% of the total nitrogen, both in the upper range of previous published values. A long-term study of N$_2$O production and emission at reactor-scale was performed at the Lynetten, the largest WWTP in DK. N$_2$O emission factor was 0.8% of the removed nitrogen at the full-scale BioDenipho line at Lynetten. Based on an LCA type evaluation, this corresponds to ~30% of the total carbon footprint of the WWTP. As a result of the intensive measuring campaign at Lynetten, 3 different control strategies to mitigate N$_2$O mitigation were developed and tested. The results were put in LCA context and the most-efficient control strategy reduced the overall CO$_2$ footprint of the plant with 18% compared to normal operation. Incubation-based determination and quantification of N$_2$O production pathways were performed on site with biomass from the BioDenipho reactors at Lynetten, using $^{15}$N labelled substrates and $^{18}$O-O$_2$. In general, heterotrophic denitrification was insignificant during oxic conditions, while incomplete denitrification became an important N$_2$O contributor under anoxia. Both pathways of ammonia oxidizing bacteria were equally important in oxic incubations with 3 mg/L O$_2$, while low oxygen concentrations favoured N$_2$O production by nitrifier denitrification over hydroxylamine oxidation. The quantitative effect of oxygen as well as other parameters on N$_2$O production pathways was linked to in situ measurements. A mathematical model structure that describes N$_2$O production during biological nitrogen removal was proposed and calibrated. The calibrated model predicts the NO and N$_2$O dynamics at varying ammonium, nitrite and dissolved oxygen levels in two independent systems: (a) an AOB-enriched biomass and (b) activated sludge (AS) mixed liquor biomass. Taken together, the observations and modelling efforts uncover different mitigation strategies to control N$_2$O emissions from biological nitrogen removal processes.